System Level Analysis of Noise and Interference Analysis for a MIMO System

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Introduction

Multiple input multiple output antenna communication system are gaining importance in the field of communication and ad-hoc networks due to increase demand for wireless throughput in band-limited channels. A system analysis is not complete without accounting for the system level noise and interference. This abstract provides a simple system level model including noise and interference to enable detailed analysis of MIMO system. Multiple-input-multiple-output systems have been studied for more than a decade, since Froschini's landmark conclusion that the theoretical information capacity increases linearly with the number of antennas for rich multipath channels [1]. Experimental characterization and model development have shown that the ideal linear capacity increase is not achievable in practice due to a number of factors including correlation of the communication channel, close antenna spacing and subsequent mutual coupling [2-4]. The capacity also depends on the type of channel state information (CSI) available. A popular expression for MIMO capacity is: [3]

$$C_{EP} = \log_2[\det(I_M + \frac{\rho}{N} hh^*)] \quad b/s/Hz \tag{1}$$

From (1) we can see that the capacity depends on SNR (ρ), channel matrix (h) and the number of antennas N. The SNR and the channel matrix are influenced by the system noise and interference

Various noise and interference models have been developed analytically or based on measurements using an information theory approach. MIMO systems are affected not only by simple additive white Gaussian Noise (AWGN), as assumed by researchers in the past [5], but also by various non-Gaussian noises and system level noises such as phase noise and timing synchronization errors. Interference is another important component that affects the performance of a MIMO system. A survey on the noise and interference models along with their advantages and short-comings is discussed in [6]. This abstract provides a detailed transmission equation for MIMO array design incorporating the noise and interference models.

MIMO system model

Literature in the past has analyzed MIMO systems from an information theory signal processing perspective [2, 3] as well as network level perspective [7]. The

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information theory based model gives a detailed signal processing perspective but fails to address some of the network level properties like mutual coupling, system noise, antenna correlation etc. The network level approach taken by Jensen and Wallace in [8] includes the components which were missing in the information theoretic approach but fail to analyze the effect of normalization and the affect of antenna efficiency on capacity. David [8] has discussed the importance of antenna normalization and efficiency and has shown the effect of these factors on capacity. Figure 1 shows a detailed MIMO transmission model which has been used for MIMO signal analysis. [8].The model can be expressed in the equation form as follows

$$y = \underbrace{\underbrace{Z_0^{1/2} \underbrace{S_{21}(I - S_{RR}S_{11})^{-1}}_{matching} \left(I + \frac{Z_{RR}}{Z_0} \right)^{-1}}_{M_R} \underbrace{E_{cdr}}_{\substack{rad \\ eff}} \underbrace{\left[\frac{1}{Z_0} \sum_{k=1}^{N_p} \underbrace{E_i^R(AOA_k, \hat{r})}_{directivity} \cdot \underbrace{\hat{p}_T}_{\substack{pol. \\ loss}} \underbrace{\beta_k}_{\substack{path \\ loss}} \underbrace{e_j^T(AOD_k)}_{directivity} \right]}_{H_{DP}} \underbrace{E_{cdt}}_{\substack{rad \\ eff}} \underbrace{\underbrace{(I - S_{TT})}_{matching}}_{M_T}}_{H} x, \tag{2}$$

Noise and interference model

Any unwanted signal that affects the performance of a communication system can be considered to be noise. A highly popular and the most commonly used noise model in communication is the additive white Gaussian noise (AWGN) model. Middleton [9] proved that the noise sources may not be always Gaussian and some of the non-Gaussian models such as the Poisson, impulse, and man-made models must be considered for better approximation of a SISO communication system. The non-Gaussian noise and interference has been classified by Middleton into classes A, B and C.

Figure 2 shows a network level model of a MIMO system that includes all the important noise contributors that add to the total system noise. On the transmitter side, the main sources of noise are the hardware noise in the amplifier, mixer and the transmitter antennas. Along with these shot noise, Johnson noise, Quantization noise and thermal noise also affect the system performance. Along with these mutual coupling affects also contribute to the noise. A few of the channel noise models which incorporate the channel effects have been studied by Boche in [10]. Boche was one of the initial researchers who in 2003 analyzed three worst case noise scenarios for multi-user MIMO communication and calculated the minimum and maximum capacity for these three cases. A complete noise model for MIMO communication should include all of the noise sources mentioned above. Let us assume that N is the total noise that reaches the receiver amplifier which can be given as

$$N = N_{thermal} + N_{mutual} + N_{phase} + N_{time} + N_{environment} + N_{AWGN} + N_{impulse} + N_{manmade} \tag{3}$$

Such a complete model has not yet been integrated into the MIMO capacity calculation. It is particularly important to analyze these noise models for wireless and ad-hoc networks where the CSI is known at the transmitter and receiver.

A wireless communication system transmits data in the environment at different frequencies. Any signal that reduces the probability of reception of the intended signal can be considered to be interfering with the signal. Various interference models have been developed and a detailed survey on the available models is provided in [6].

Proposed model

Building on the MIMOtransmission equation in (2) [from 8], we can model the noise and interference in a similar fashion to estimate the SNR and calculate the MIMO capacity. The noise can be modeled as a summation of noise terms and is given by

$$NI = N_{thermal} + N_{mutual} + N_{phase} + N_{time} + N_{environment} + N_{AWGN} + N_{impulse} \\ + N_{manmade} + Interference \tag{4}$$

.

The second method for performing the interference and noise analysis is

$$NI = \sum_{J=1}^{L-1} \sqrt{\eta_{L,j}} H_{L,j} x_j + Noise \tag{5}$$

where $H_{L,j}$ and x_j represent the normalized channel matrix and normalized transmitted signal of user j, respectively. The noise vector and channel matrix have independent and ideally distributed zero mean and unit variance complex Gaussian entries. ρ_L is the signal to noise ratio of user L. Hence the total SNR expression can be written as

$$SNR = \frac{y}{NI} \tag{6}$$

The results obtained by using equation (4),(5), and (6) for indoor, outdoor, and intra-vehicular channels will be presented at the conference.

Conclusion

The abstract provides the framework for a detailed system level noise and interference model which can be used for analysis of any MIMO or ad-hoc network. The system level analysis helps in understanding the major sources of noise and interference and helps in optimizing interference and noise mitigation algorithms based on the major noise and interference sources.

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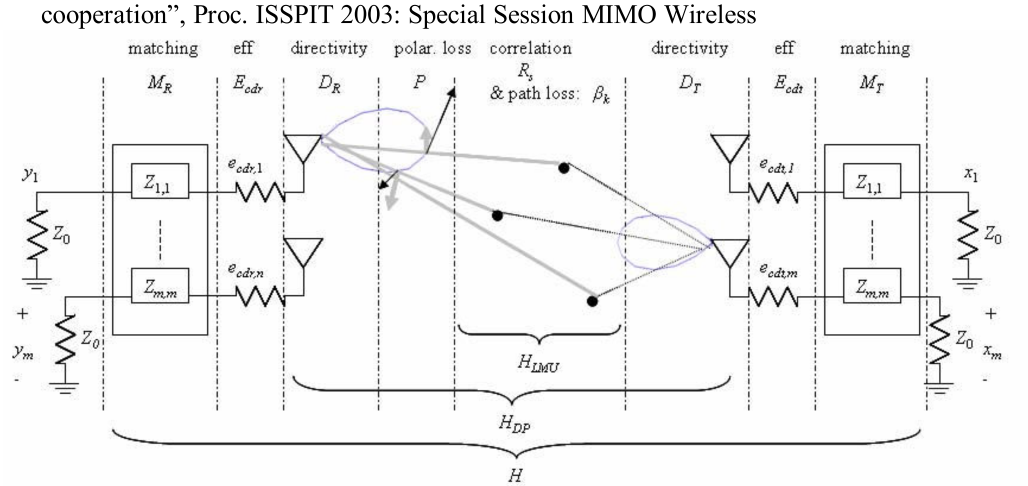

Fig.2 A general MIMO system mode

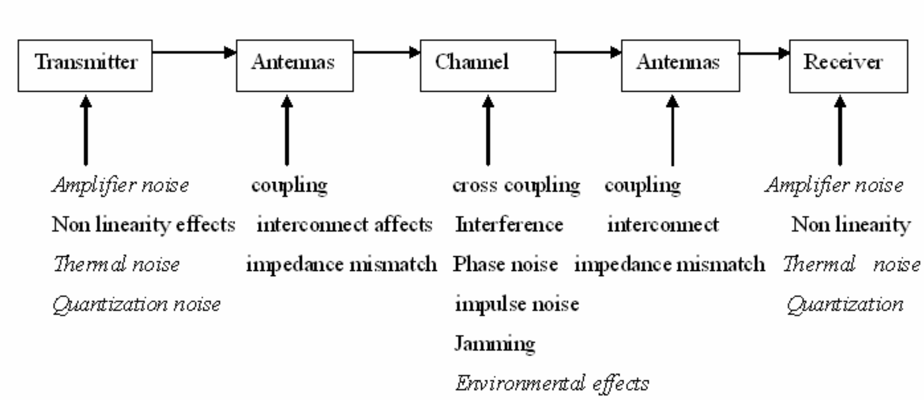

Figure 1. Noise and interference sources in a communication system